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MODELING OF BARREL/PROJECTILE INTERACTION IN A ROTATING BAND

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JUNE 2001

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The ABAQUS program was used and a refined finite element mesh was chosen to complete the modeling of the barrel/projectile interaction in a rotating band. The calculations for the engraving processes proceeded until the projectile had passed completely through the forcing cone in the land and groove. The axially symmetric cases were considered and the elasticity of the tube and projectile was neglected. Sliding friction was considered and the copper band was either elastic-plastic or ideally plastic. The magnitude and distribution of the contact pressure between the band and the tube were obtained during and after engraving. For the first time we have observed the opening of a gap between the band and the bore after engraving was completed, even when we observed full contact in the forcing cone.

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INTRODUCTION

Earlier research has indicated that most cases of rotating band failure can be attributed to excessive wear (deformation) in the initial portion of the projectile's travel, even when the failure does not occur until well down the tube (ref 1). When the projectile enters the barrel of the gun, the rotating band passes through a forcing cone that places it under compressive interference stresses. Thus, large plastic deformation occurs along the driving edges of the forcing cone. The radial pressure between the projectile band and bore produces friction and an abrasive action on the bore surface. Previously, the rigid-plastic flow theory, assuming uniform distribution, was used to obtain approximate theoretical estimates of radial band pressure (refs 2,3). A satisfactory stress analysis of the engraving process and wear has never been reported. However, in an earlier paper (ref 4), a two-dimensional elastic-plastic analysis of the engraving process in a projectile rotating band was obtained by using the finite element program—ABAQUS. The modeling for the engraving through the groove was completed, but not for the engraving through the land. The later calculations ended before the projectile passed through the forcing cone.

In this report, we have completed the modeling for the engraving process through the land and groove. A refined finite element mesh was chosen and the new version of the ABAQUS program (ref 5) was used. The calculations proceeded until the projectile had passed completely through the forcing cone. The axially symmetric cases, such as smooth bores, were considered and the elasticity of the tube and projectile was neglected. The copper band was considered as elastic-plastic or ideally plastic. An appropriate coefficient of sliding friction was also chosen. The magnitude and distribution of the contact pressure between the band and the tube were obtained as the projectile traveled through the forcing cone and farther down the tube. The magnitude of the band pressure was very large and the plastic deformation in the band was very severe. For the first time, we have observed the opening of a gap between the band and the bore after engraving was completed, even when we observed full contact in the forcing cone. A theoretical estimate for the average band pressure of an ideal plastic material was also obtained for comparison with our numerical results of band pressure.

FINITE ELEMENT MODELING

Geometry

Figure 1 shows a schematic diagram of the tube/projectile interaction in a forcing cone. The geometry of the gun system XM297/M549 was chosen for this study. The rotating band is of axial length L_o = 37.084-mm and radial thickness B_o = 2.3114-mm. The radius of the projectile is R_p = 76.581-mm and the band is attached to the projectile. The radius of the bore behind the forcing cone is R_o = 79.38-mm with the length of the forcing cone at L_c = 40.54-mm. The radii of the bore after the forcing cone through the groove and land are R_g = 78.74-mm and R_l = 77.485-mm, respectively. Therefore, the reductions in thickness through the groove and land are 6.6% and 60.9%, respectively. For this study, a simple mesh of the band was constructed of 281 nodes and 250 four-node bilinear elements (ref 4). Figure 1 also shows the old mesh #1 and new mesh #2 for the band. The new finite element mesh consists of 510 nodes, 400 CAX4H elements, and 100 CAX3H elements.

Material

The tube and projectile are assumed to be rigid, and the copper band is considered as either elastic-plastic or ideally plastic. The values of Young's modulus and Poisson's ratio for the copper are 110 GPa and 0.33, respectively (ref 6). The initial yield stresses in compression and shear are 314 MPa and 181 MPa, respectively. For an elastic-plastic hard copper band, the dependence of the yield stress upon the plastic strain in the plastic range is piece-wisely defined by the data points (314 MPa, 0.0), (620 MPa, 0.126), and (620 MPa, 10.0), and the flow stress is 620 MPa. For an ideally-plastic soft copper band, the flow stress is 314 MPa.

Boundary Conditions

We assume no separation between the band and the projectile because the band was welded to the projectile. In addition to sliding contact between the band and the tube in the forcing cone, the band may be deformed to slide axially in either direction against the projectile faces. The coefficient of sliding friction was assumed to be 0.01 for the band/tube pair.

Force/Displacement

Initially, the back face of the band is assumed to be only 40.0-mm behind the entrance of the forcing cone, whose length is 40.54-mm. Therefore, when the projectile travels 80.54-mm, the band will have passed the forcing cone and the engraving process will be considered complete. The prescribed displacement used in this nonlinear analysis is 100-mm for the groove engraving and 150-mm for land engraving.

ENGRAVING THROUGH GROOVE

The initial thickness of the band is $B_o = 2.3114$-mm, and the final thickness of the band after passing through the groove will be $B_g = R_g - R_p = 78.74\text{-mm} - 76.581\text{-mm} = 2.159$-mm. Therefore, the reduction in areas through the groove is

$$A_g = [1 - B_g*B_g/(B_o*B_o)] \times 100\% = 12.8\% \qquad (1)$$

Using mesh #1, it takes 81 increments to complete the ideally-plastic analysis, but it takes only 49 increments to complete the elastic-plastic analysis. Figure 2 shows the contact pressure and the deformed mesh after the elastic-plastic band has traveled 100-mm. Larger plastic deformation occurs at the front and back ends near the band/projectile interface. The maximum equivalent plastic strain is 2.233 at the back end close to the band/projectile interface. The distributions of the contact pressure between the tube and the band at different stages of traveling through the groove are shown in Figures 3 and 4, respectively, for the ideally-plastic and the elastic-plastic cases. The maximum value of contact pressure is 1849 MPa in the ideally-plastic band and 3548 MPa in the elastic-plastic band. It is interesting to point out that the maximum value of contact pressure/flow stress is 5.89 and 5.72, respectively, for the ideally-plastic and elastic-plastic cases.

ENGRAVING THROUGH LAND

The initial thickness of the band is B_o = 2.3114-mm, and the final thickness of band after passing through the land will be $B_l = R_l - R_p$ = 77.485-mm - 76.581-mm = 0.904-mm. Therefore, the reduction in area through the land is

$$A_l = [1 - B_l * B_l / (B_o * B_o)] \times 100\% = 84.7\% \qquad (2)$$

Using the old mesh #1, it takes 268 increments to travel 49.4-mm for the ideally-plastic band, but it takes 227 increments to travel 49.7-mm for the elastic-plastic band. The computation ends because the time increment required is less than the minimum (0.001-mm) specified. Plastic deformations are very large and severe distortions have occurred, especially at the front and back ends near the band/projectile interface. The distortions are so severe that computation stops. The maximum equivalent plastic strain is 57.58 at the front end. This value of plastic strain is so large that some failure criterion has to be introduced. The distributions of the contact pressure between the tube and the band at different stages of traveling through land in the forcing cone are shown in Figures 5 and 6, respectively, for the ideally-plastic and elastic-plastic cases. The maximum value of contact pressure is 3505 MPa in the ideally-plastic band and 6991 MPa in the elastic-plastic band, as shown in the figures. It is interesting to point out that the maximum value of contact pressure/flow stress is 11.16 and 11.28, respectively, for the ideally-plastic and elastic-plastic cases.

Using the new mesh #2, we have carried out the computations for the projectile to travel 150-mm. It takes 3636 increments to complete for the ideally-plastic band and 4643 increments for the elastic-plastic band. The maximum value of contact pressure/flow stress is 11.66 and 11.29, respectively, for the ideally-plastic and elastic-plastic cases. It occurs during engraving. When the projectile travels 80.54-mm, the band will have passed the forcing cone and the engraving process will be considered complete. The numerical results for the elastic-plastic case are shown in Figures 7 through 12. Before the band has passed the forcing cone, the contact pressure and deformation in the band during engraving are shown in Figures 7 and 8, respectively, for 61.17-mm and 76.74-mm travel. The band is in complete contact with the tube, and two points on the band/projectile interface (C and D) represent the front and back ends of the band. Plastic deformations are very large and severe distortions have occurred especially at the front and back ends near the band/projectile interface. When the projectile travels 80.54-mm, the band will have passed the forcing cone. The contact pressure and deformation in the band are shown in Figures 9 and 10, respectively, for 115.89-mm and 150.00-mm travel. Now the distortions are more severe and the values of contact pressure become smaller, but the distributions are quite different from earlier stages. For the first time, we have observed the opening of a gap between the band and the bore after the band has passed the forcing cone. The magnitudes and locations of the gap are shown in Figures 11 and 12, respectively, for 115.89-mm and 150.00-mm travel. After the band has traveled 150.00-mm , the maximum value of contact pressure/flow stress is 7.58 and 7.24, respectively, for the ideally-plastic and elastic-plastic cases.

THEORETICAL ESTIMATE OF BAND PRESSURE

All theoretical estimates were trying to obtain the average band pressure for an ideal plastic material. An approximate formula for the average band pressure at the instant of complete engraving (ref 7) is

$$P/Y = 2.97[W_l/(W_l + W_g)] + 0.29\ W/T \tag{3}$$

where Y, W_l, W_g, W, and T are yield (flow) stress, land width, groove width, final band width, and band thickness, respectively. The value of 2.97 corresponds to the indentation pressure on the tops of the lands, assuming the rifling is a rigid material pressing into an ideal plastic band (ref 8). The bracketed factor, $W_l/(W_l + W_g)$, averages the pressure acting on the lands over the entire bore surface. The additional term corresponds to the average pressure exerted by two rigid plates squeezing an ideal plastic material (ref 9). If we assume $W_l = W_g$, $W = 5.2$-mm, and $T = (B_g + B_l)/2 = 1.532$-mm, then $P/Y = 2.47$.

DISCUSSION AND CONCLUSION

The contact pressure between the band and tube has been obtained as the projectile travels through the forcing cone and farther down the tube. The distribution is nonuniform, and the magnitude of the band pressure is very large. Although the magnitudes for the elastic-plastic band are quite different from those for the ideally-plastic band, the maximum values of contact pressure/flow stress (P/Y) are about the same according to our numerical results. The maximum P/Y is about 5.8 for engraving through groove and about 11.5 for engraving through land. When the engraving is completed, the maximum P/Y reduces to about 7.5 in the land. The average values of P/Y during engraving are estimated to be 50% of the maximum, i.e., 2.9 through groove and 5.8 through land. It is reasonable that these average values based on calculations are larger than the theoretical estimate 2.47. The calculated values that were based on sliding through the forcing cone should be larger than the theoretical estimate that was based on indentation because more deformation energy is required for sliding.

Based on the comparison with theoretical estimate for the band pressure, we conclude that the calculated finite element results are reasonably accurate. The two-dimensional modeling could be used for discussing the effects of geometry, material properties, and friction on the band. We can determine the maximum contact pressure and also observe the deformation in the band. The three-dimensional simulations are still very difficult now.

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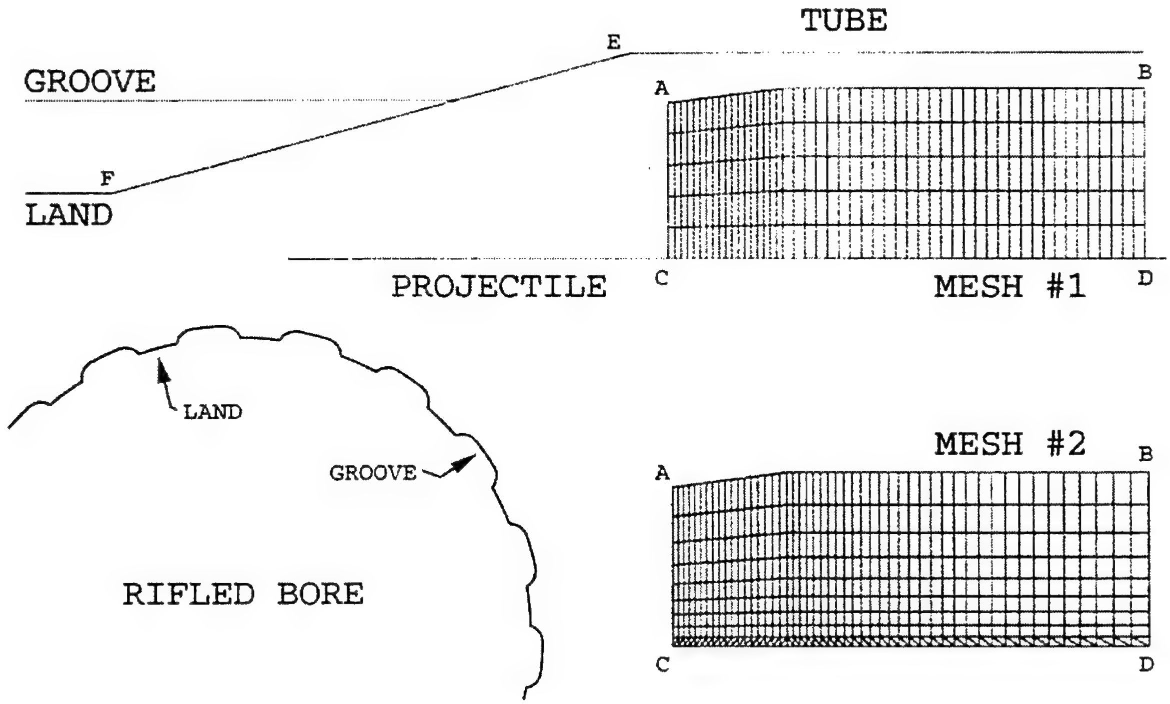

Figure 1. Schematic diagram of tube/projectile interaction in a forcing cone and finite element meshes for the band.

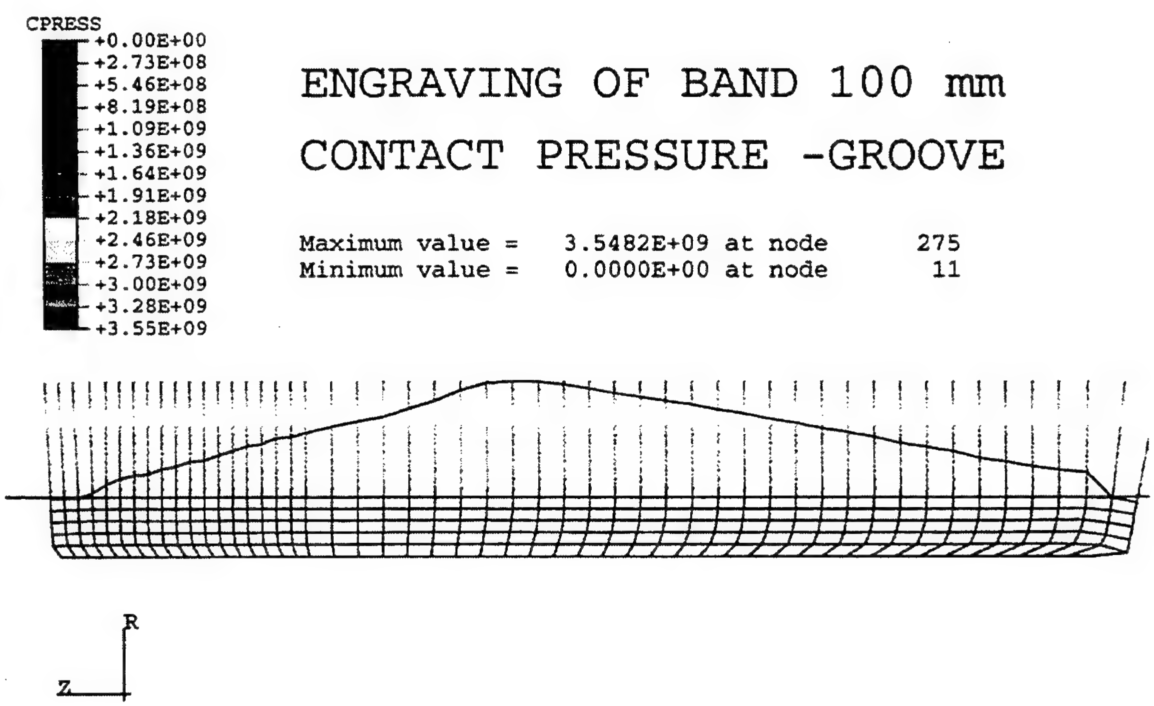

Figure 2. Contact pressure between tube and band after traveling 100-mm through groove.

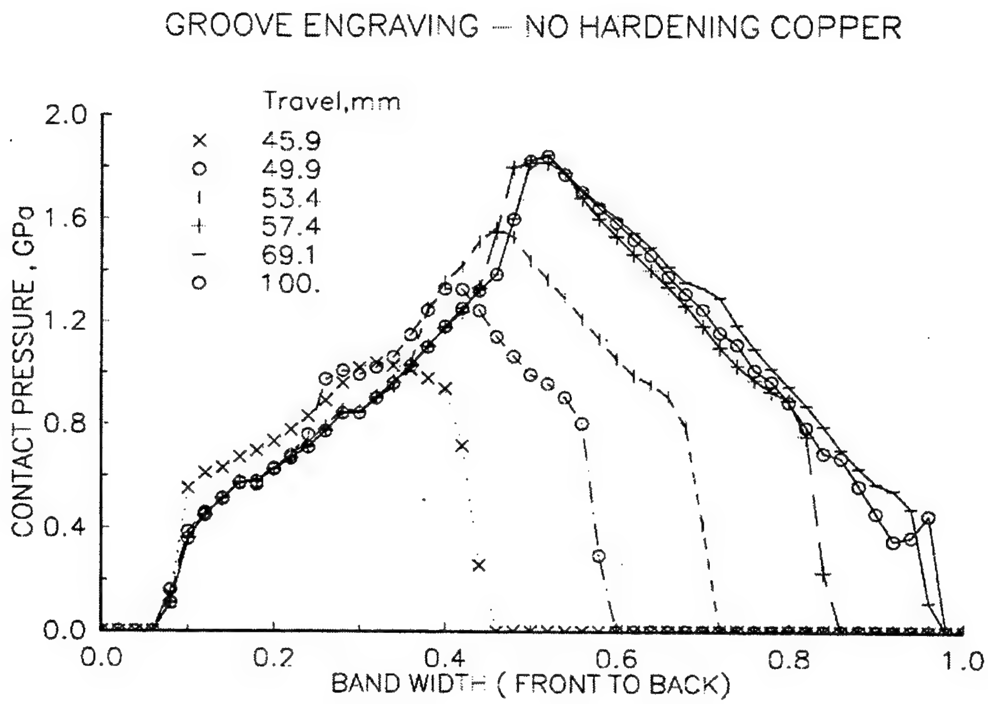

Figure 3. Contact pressure during groove engraving in a nonhardening copper band.

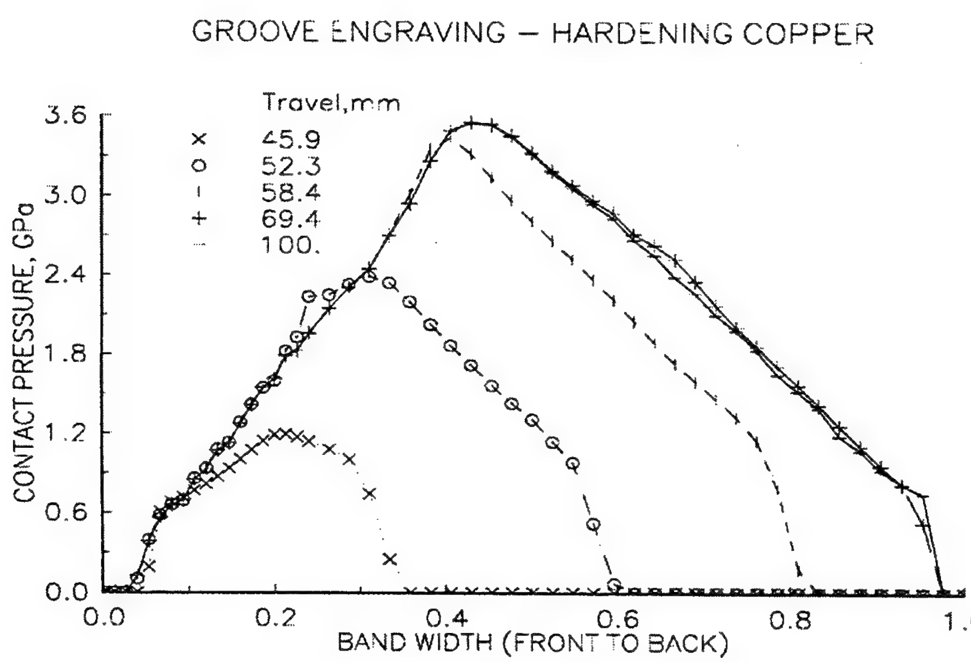

Figure 4. Contact pressure during groove engraving in a hardening copper band.

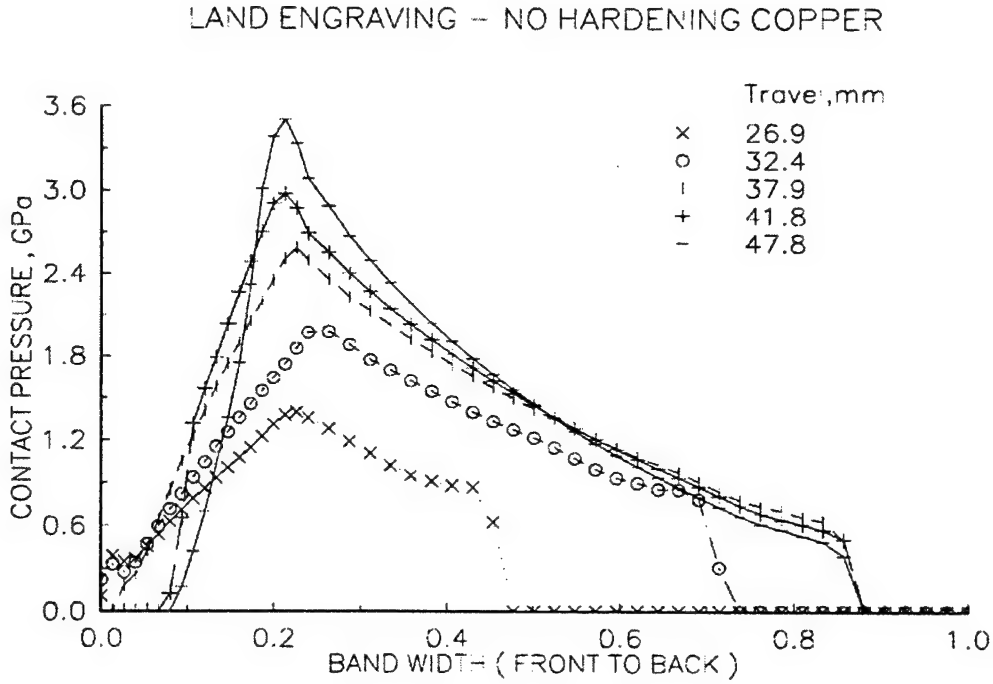

Figure 5. Contact pressure during land engraving in a nonhardening copper band.

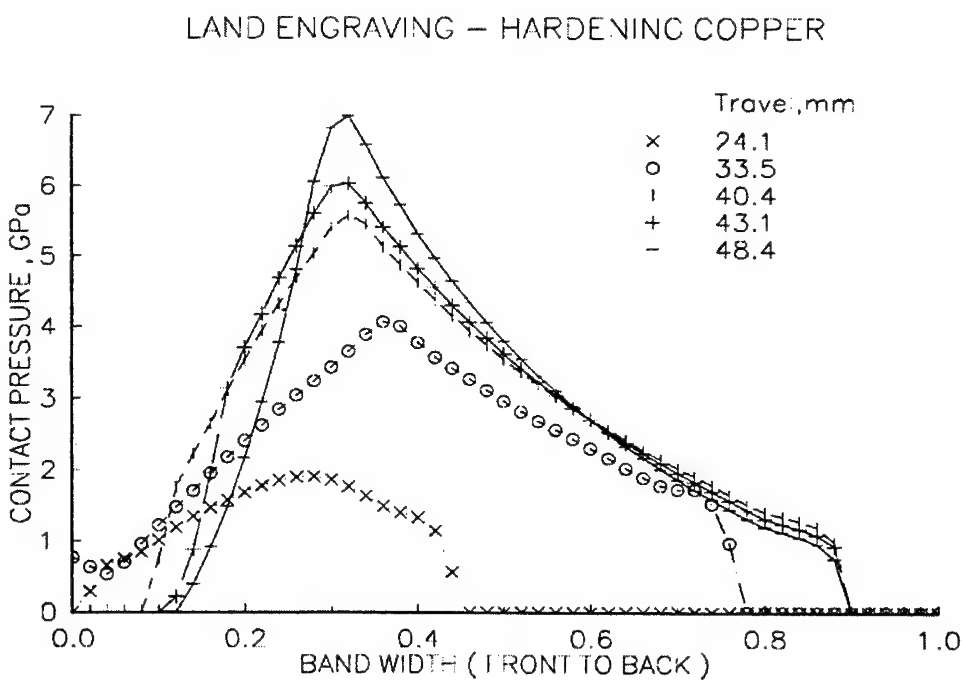

Figure 6. Contact pressure during land engraving in a hardening copper band.

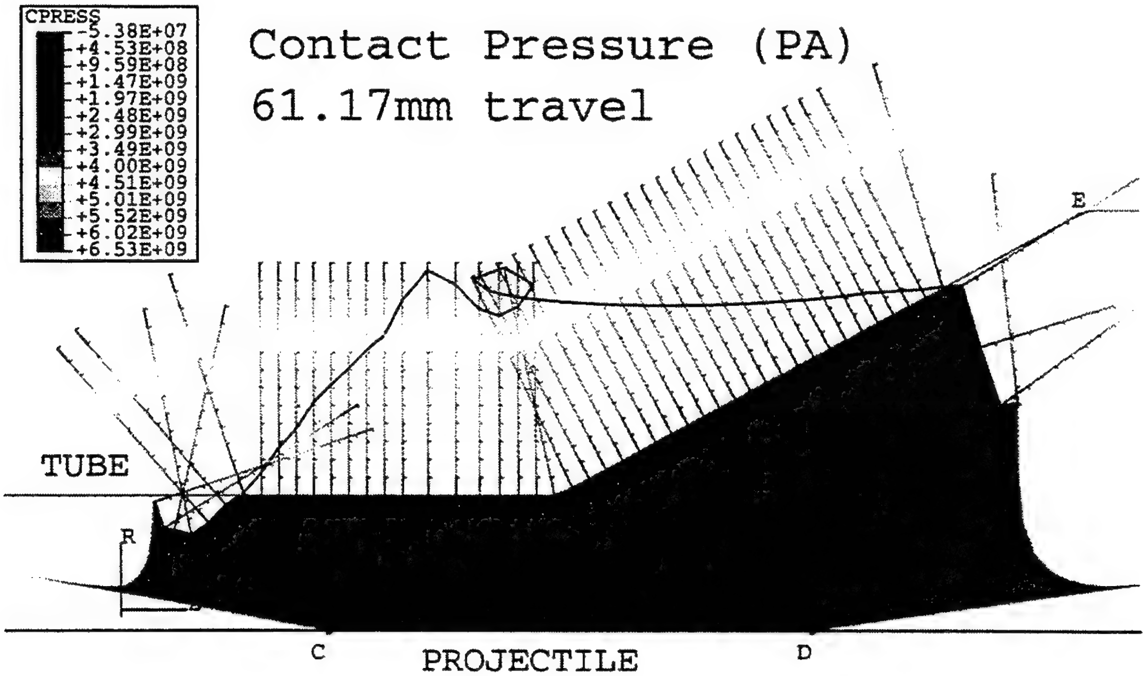

Figure 7. Contact pressure and deformed band after traveling 61.17-mm through land.

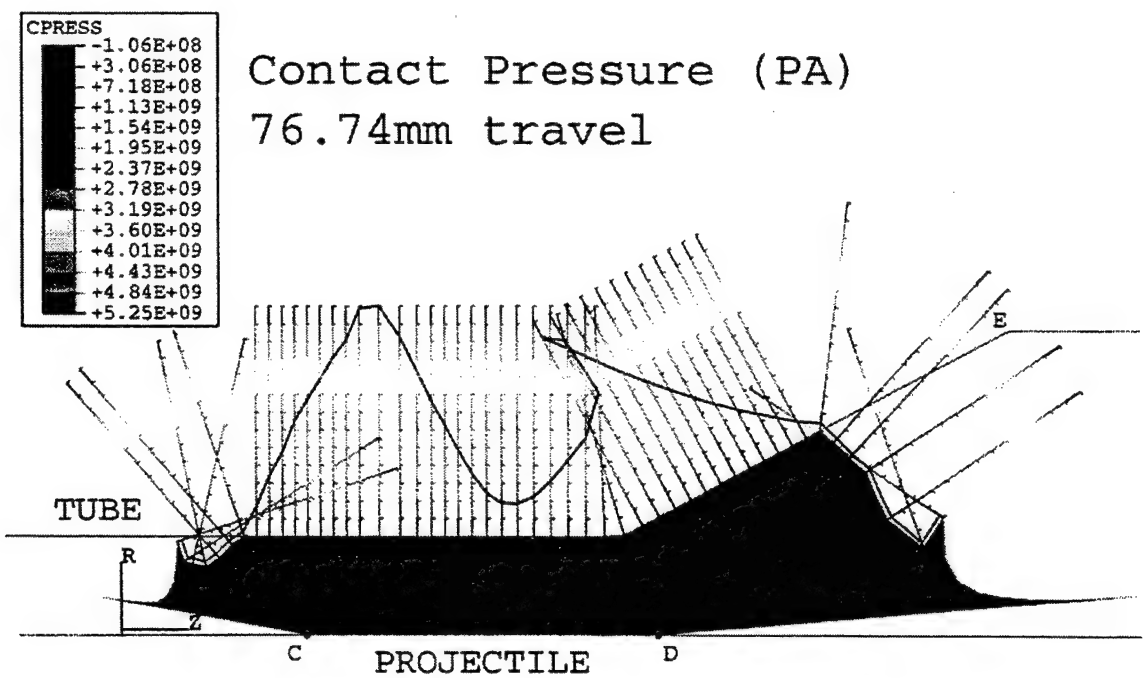

Figure 8. Contact pressure and deformed band after traveling 76.74-mm through land.

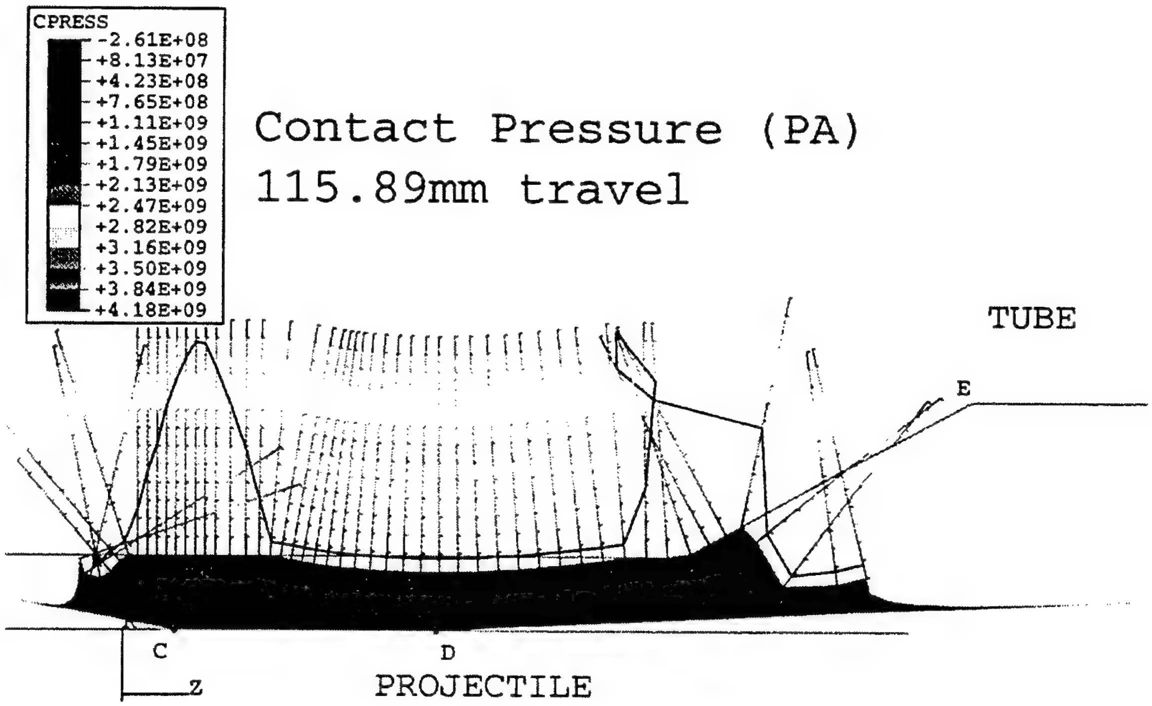

Figure 9. Contact pressure and deformed band after traveling 115.89-mm through land.

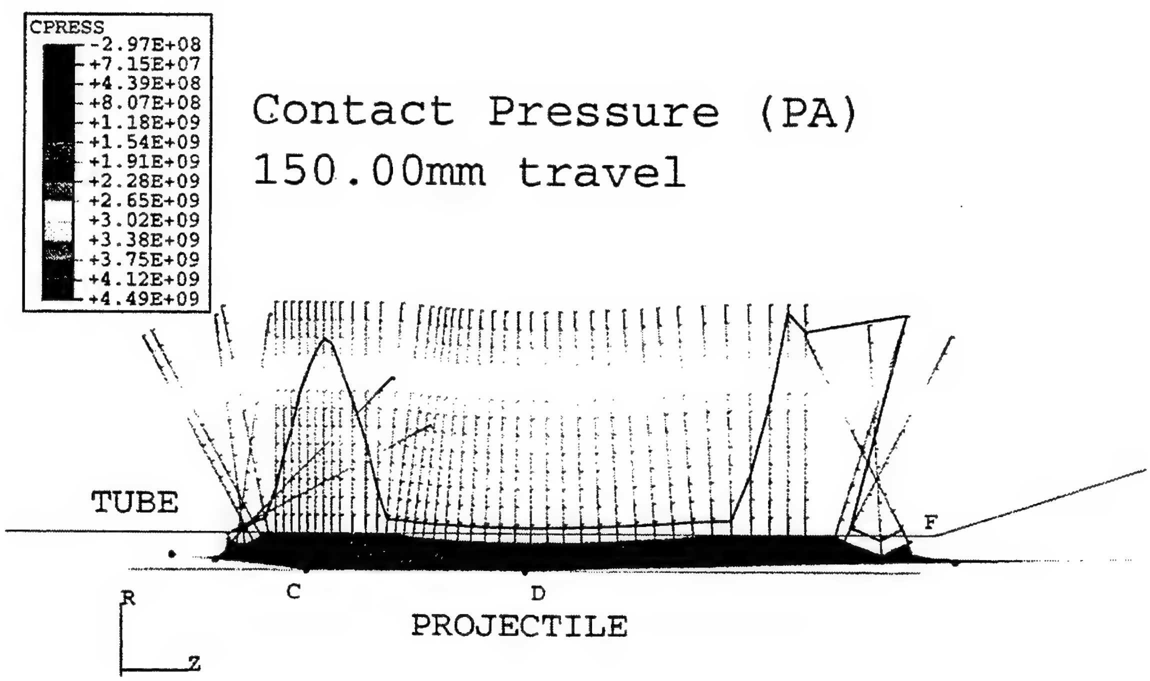

Figure 10. Contact pressure and deformed band after traveling 150-mm through land.

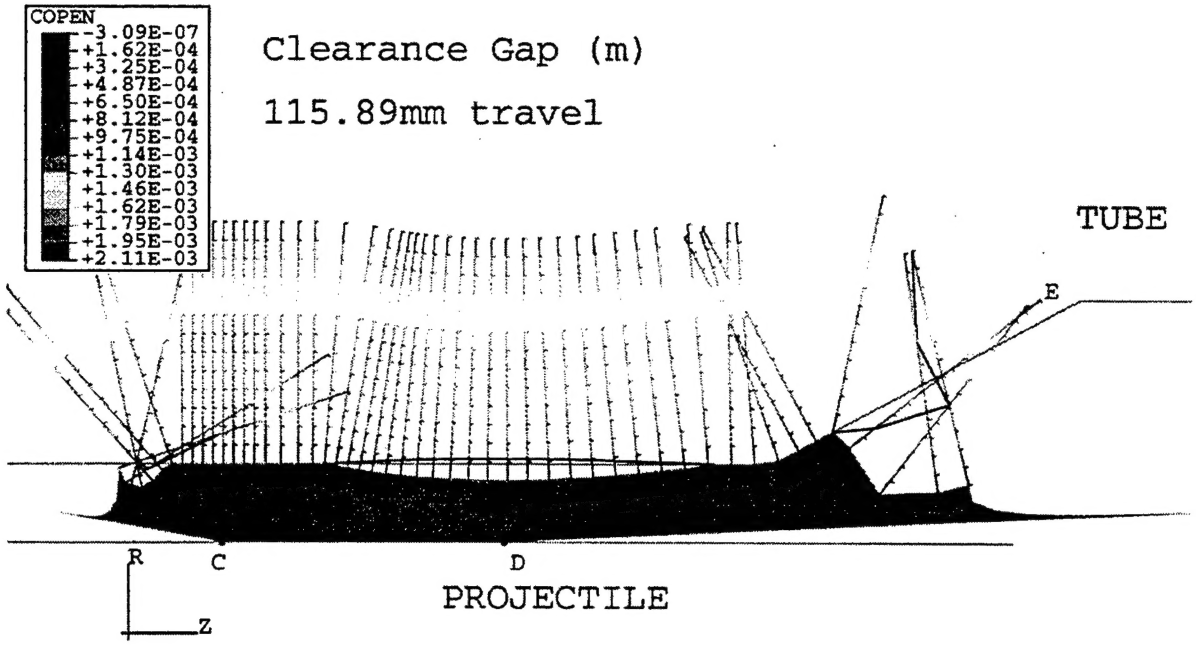

Figure 11. Gap between band and barrel after traveling 115.89-mm through land.

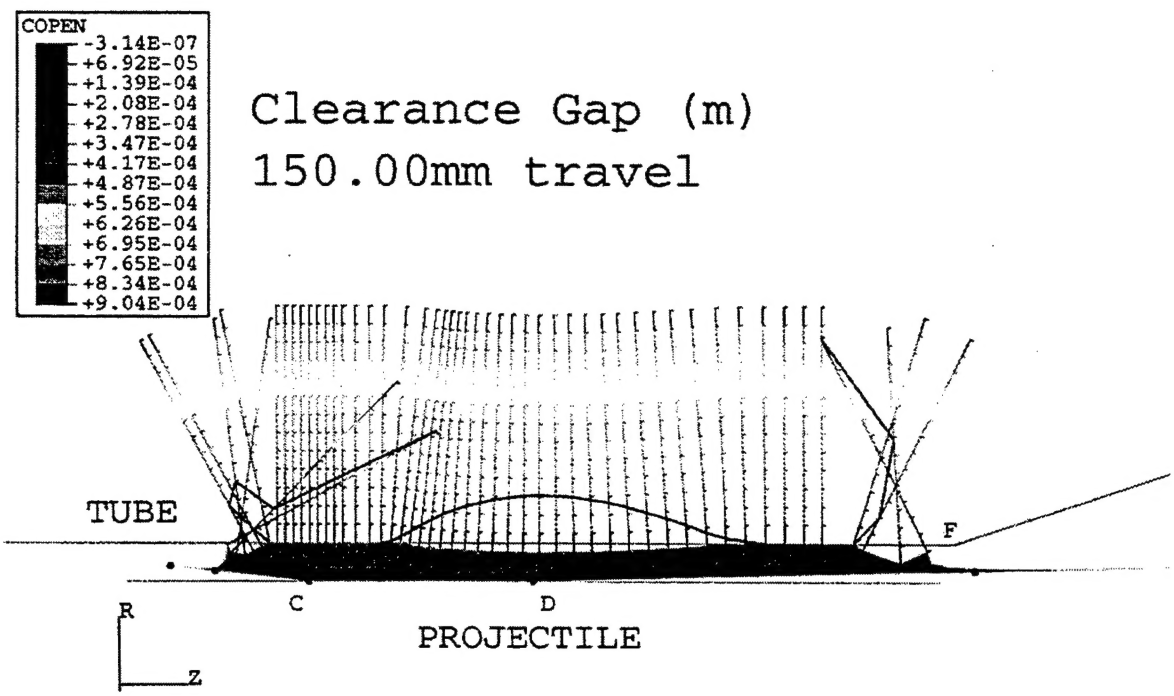

Figure 12. Gap between band and barrel after traveling 150-mm through land.

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